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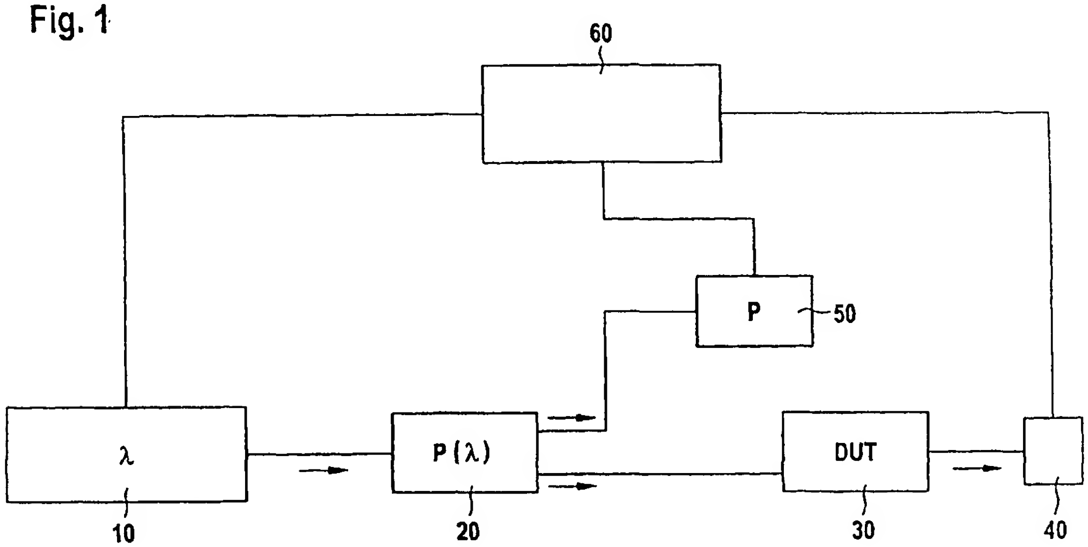
(54) Measurement of polarization dependent characteristic of optical components

(57) For measuring a polarization dependent parameter of an optical device under test - DUT - (30), an optical source (10) provides an optical stimulus signal at variable wavelengths, and a polarization translator (20) translates the polarization state of the optical stimulus signal applied from the optical source (10) at its input to its output in a deterministic way dependent on the wavelength of the optical stimulus signal. A receiving unit (40) receives an optical response signal from the DUT (30) to the applied optical stimulus signal, and an analyzing unit (60) analyzes received optical response signals for different wavelengths for determining values of the polarization dependent parameter of the DUT (30).

Fig. 1



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Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to testing of optical components in particular for communication systems.

[0002] Measurement of polarization dependent parameters like polarization dependent loss (PDL) and polarization dependent group delay PDGD (covering Differential Group Delay DGD and Polarization Mode Dispersion PMD) is of increased importance for advanced communication systems and generally described in 'Fiber Optic Test and Measurement' by Dennis Derickson, ISBN 0-13-534330-5, 1998, pages 354ff. Especially long-haul high-speed systems require that polarization properties of its components fulfill certain requirements. In general, component manufacturers address this by 100% testing of components for critical parameters. PDL nowadays in many cases is already measured 100%, PDGD may also develop to be a 100% test in manufacturing.

[0003] Today's solutions for measuring polarization dependent loss parameters are the scrambling method (applying a random variation of polarization states and comparing maximum with minimum determined loss) or the Mueller method, whereby 4 defined polarization states are measured for each wavelength point and analyzed together. The latter requires multiple measurement sweeps at predefined polarization states. These methods are either slow, if testing at multiple wavelengths is required (PDL measurement using the scrambling method), or require multiple measurement sweeps at predefined polarization states (Mueller method). Multiple sweeps are disadvantageous because measurement time is increased and require very high stability of the measurement setup because no change of polarization properties of the whole setup (between laser and DUT) is allowed between the sweeps.

SUMMARY OF THE INVENTION

[0004] It is an object of the invention to provide an improved measurement of polarization dependent parameters. The object is solved by the independent claims. Preferred embodiments are shown by the dependent claims.

[0005] For measuring polarization dependent parameters of an optical device under test (DUT), an optical source (preferably a tunable laser) provides an optical signal through an optical polarization translator to the DUT. The polarization translator translates the polarization of the optical signal from its input to its output in a deterministic way dependent on the wavelength of the optical signal.

[0006] The polarization translator provides the translation of the polarization dependent on the wavelength preferably using birefringent properties. Accordingly, the optical source may also provide a variation of the wavelength over the time, and polarization translator provides a variation of the polarization over the time, so that effectively the translator also provides a 'translation' of the polarization dependent on the wavelength. The parameters wavelength and frequency shall be regarded here as equivalents (related by the general equation $f = c/\lambda$).

[0007] When varying the wavelength of the optical source, the polarization translator changes the polarization of the signal launched into the DUT. Tuning the wavelength of the optical source in a way that measurement points with different polarization states are covered thus allows determining polarization dependent parameters of the DUT in that particular wavelength range.

[0008] Typical polarization dependent parameters that can be analyzed by the invention are polarization dependent loss (PDL) or polarization dependent group delay PDGD (also referred to as Differential Group Delay (DGD) or Polarization Mode Dispersion (PMD)).

[0009] The uncertainty of the polarization state of the output signal may be reduced by tapping off some fraction of the signal in an appropriate way and analyzing its polarization state at each wavelength with a polarimeter or a reduced polarization analysis device like an Analyzer.

[0010] The polarization translator may be purely passive. The optical signal is preferably provided that it does not hit a Principle State of the Polarization (PSP) of the polarization translator, so that the output signal will follow a trajectory (e.g. a circle) on the Poincare Sphere in a deterministic way.

[0011] The same principle of scanning the polarization can be applied to various PMD measurement techniques: For example the Jones Matrix Eigenanalysis (JME) or a novel method which is outlined in the European Patent Application No. 125089.3 (EP 1113250). In case of PMD measurements in general only two polarization states are combined to a measurement value.

[0012] In case that several measurement points (defined by the wavelength and the polarization state of the optical signal applied to the DUT) are to be analyzed together for determining a value of a polarization dependent parameter, the wavelength range for those measurement points is preferably selected that a value of the polarization dependent parameter of the DUT can be considered as substantially constant in that wavelength range.

[0013] Preferred algorithms for analyzing together several such measurement points are interpolation of neighboring measurement points, combining 4 measurement points using the Mueller Matrix analysis, or combining 2 measurement points using e.g. the Jones Matrix analysis.

[0014] The invention has various advantages compared to today's standard methods (polarization scrambling and Mueller Matrix analysis). The polarization transformation device may be purely passive, the number of measurement points can be chosen to be much smaller compared to the scrambling method, and, most important, the complete measurement can be performed within one sweep (instead of four for the Mueller Matrix Analysis). Thus, the invention allows fast measurements and is also less sensitive against e.g. environmental or mechanical disturbances.
[0015] The invention can be partly or entirely embodied or supported by one or more suitable software programs, which can be stored on or otherwise provided by any kind of data carrier, and which might be executed in or by any suitable data processing unit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Other objects and many of the attendant advantages of the present invention will be readily appreciated and become better understood by reference to the following detailed description when considering in connection with the accompanied drawings. Features that are substantially or functionally equal or similar will be referred to with the same reference sign(s).

Fig. 1 shows a measurement setup according to the invention for measuring polarization dependent parameters.

Fig. 2 shows a representation of polarization transformation on Poincare Sphere.

Figs. 3 and 4 show embodiments of the polarization translator.

DETAILED DESCRIPTION OF THE INVENTION

[0017] In Fig. 1, a tunable laser 10 as an optical source provides an optical signal through an optical polarization translator 20 to an optical device under test (DUT) 30. A power meter 40 receives and detects the optical signal after passing the DUT 30. The polarization translator 20 translates the polarization of the optical signal from its input to its output in a deterministic way dependent on the wavelength of the optical signal.
[0018] A polarization analyzer 50 might be optionally coupled to the output of the polarization translator 20 in order to determine the polarization state of the output signal of the polarization translator 20.
[0019] A controller 60 is coupled to the power meter 40 for analyzing polarization dependent parameters. Preferably, the controller 60 is further coupled to the tunable laser 10 for controlling the application and variation of the provided an optical signal and to the polarization analyzer 50 for receiving information about the actual polarization state of the output signal from the polarization translator 20.
[0020] When varying the wavelength of the tunable laser 10, the polarization translator 20 changes the polarization of the optical signal launched into the DUT 30. In operation, the wavelength of the tunable laser 10 is tuned in a way that optical signals with different polarization states are provided to the DUT 30. For each measuring point (defined by the wavelength and the polarization state of optical signal applied to the DUT 30), the controller 60 receives a value of power intensity determined by the power meter 40. Analyzing the power intensity values for a plurality of different measuring points thus allows determining polarization dependent parameters of the DUT 30 such as polarization dependent loss (PDL).
[0021] In a preferred embodiment, several measurement points will be analyzed together for determining a value of a polarization dependent parameter. The wavelength range for those measurement points is selected that a value of the determined polarization dependent parameter of the DUT can be considered as substantially constant in that wavelength range.
[0022] Preferably, a set of four measurement points with different polarization states is analyzed together resulting e.g. in one PDL value for the DUT. The wavelength range of the set of measurement points is thereby preferably selected to be smaller than the wavelength resolution for that measurement. In an example wherein PDL measurements are desired with a spectral resolution of 1pm, a set of measurement points with 4 different polarizations should have a spectral distance of 0.25pm. Within such wavelength range (even going further up to say 10 pm) it can be seen as sufficiently ensured with typical DUTs of present optical networks that constant PDL properties are maintained in that range.
[0023] Fig. 2 shows a representation of polarization transformation on Poincare Sphere. The polarization state P_{in} of the optical signal applied to the polarization translator 20 will be transformed to polarization states P_i^{out} (with i = 1, 2, 3, ...) at the output of the polarization translator 20. In case of a waveplate (which shows purely linear birefringence) as polarization translator 20 with an orientation O, the polarization states P_i^{out} are all located on a circle on the Poincare Sphere dependent on the wavelength λ of the optical signal.
[0024] The polarization translator 20 can be implemented in several ways depending on requirements of the particular

measurement to be conducted. If a PDL measurement is to be performed with a Mueller Matrix type of implementation (see for example on pages 356ff in 'Fiber Optic Test and Measurement' by Dennis Derickson, ISBN 0-13-534330-5, 1998), a set of at least four measurements has to be made with polarization states fulfilling certain requirements: they have to be significantly different, must not be located on a great circle of the Poincare Sphere, and preferably should not be located on any circle on the Poincare Sphere. A very high order waveplate that is excited by the linearly polarized signal of the tunable laser 10 can be used. The angle between the polarization of the optical signal and the optical axis of the waveplate is defined to ϕ_1. However, in this configuration the states of polarization P_i^{out} are located on a circle that under certain circumstances won't allow conducting the Mueller Matrix type of calculation. This problem can be avoided if at least two waveplates are concatenated with their principle state of polarization PSP not aligned. This configuration would provide second order PMD, which means that the trajectory of the polarization translation function on the Poincare sphere won't be a circle anymore.

[0025] In contrast to the Mueller Matrix based PDL measurement the PMD measurement techniques mentioned before only require measurement on 2 states of polarization. There are no requirements for these States of Polarization as long as they are sufficiently different.

[0026] In a preferred implementation, a high order waveplate as the polarization translator 20 creates a phase difference between the propagating modes by its birefringence. An angle α_1 represents the phase difference of the two optical signals propagating in the two Eigenmodes of the waveplate device. When entering the device the phase difference is $\alpha_1=0$. When exiting the angle is given by:

$$\alpha_1 = \frac{2\pi}{\lambda}\,\Delta n \cdot L \qquad \text{(Equation 1)}$$

with Δn, λ, L representing the difference of the refractive indices of the two propagating polarization modes, the optical wavelength and the length of the device, respectively. If the length L of the birefringent device 20 is kept fixed and dispersive effect are neglected (which means Δn is constant over wavelength), the wavelength increment to increase α_1 by a given amount, say $\Delta\alpha_1$ is given by:

$$\Delta\lambda \approx \frac{\Delta\alpha_1 \cdot \lambda^2}{2\pi \cdot \Delta n \cdot L} \qquad \text{(Equation 2)}$$

[0027] For example, if PMD measurement values are required with a spectral resolution of 1nm (as it may be sufficient for fused couplers as DUT 30), measurement values should be taken with an interval of 0.5nm. From Equation 2, a condition (at λ=1.5μm) for the polarization transformer 20 can be derived:

$$\Delta n \cdot L \equiv \frac{\Delta\alpha_1 \cdot \lambda^2}{2\pi \cdot \Delta\lambda} \cong 2.3 \cdot 10^{-3}\ m \qquad \text{(Equation 3)}$$

[0028] This requirement could be fulfilled with for example a $LiNbO_3$ waveguide or a birefringent fiber as the polarization translator 20.

[0029] In a $LiNbO_3$ based polarization transformer 20, a Ti diffused waveguide can be implemented perpendicular to the c-axis (optical axis) of the $LiNbO_3$ crystal (typically selected: x- or y-cut). In this configuration, the waveguide 20 has a high birefringence of $\Delta n \approx 0.079$ with a beat length L_B of the two propagating modes of:

$$L_B = \frac{2\pi}{\lambda} \cdot \Delta n \approx 21\mu m \qquad \text{(Equation 4)}$$

around λ=1.55 μm. Therefore the requirement mentioned in Equation 3 can be fulfilled with a $LiNbO_3$ waveguide 20 of a length of about 3 cm.

[0030] A polarization transformer 20 based on Polarization Maintaining Fiber (PMF) has a typical birefringence of about 10^{-3}. As this is much lower than in $LiNbO_3$, a much longer length is required: 2.25m. By increasing the length even further, a higher spectral resolution can be achieved. However, typical DWDM component test applications would require a spectral resolution of the PDL and PMD measurement around 1...3pm. Therefore a PMF fiber length of more than 1000m would be required, which might not be applicable for some applications e.g. for price, volume and possibly stability reasons.

[0031] In a further preferred implementation, an 'artificial birefringent device' 200 is used as polarization transformer 20 creating enough delay between the two propagating polarization modes for very high spectral resolution. The in-

coming (linearly polarized) light is split up in the artificial birefringent device 200 and guided along two different paths having different path lengths with a length difference ΔL. The artificial birefringent device 200 further provides the light returning from the two paths with orthogonal states of polarization. This can be done e.g. by splitting up the incoming light polarization dependent or by changing the state of polarization at least in one of the paths. After recombining the light returning from both paths, the state of polarization of the combined signal depends on the wavelength (or more accurately the frequency) of the optical signal in a deterministic, periodic way. By adjusting the length difference ΔL the periodicity can be broadly varied.

[0032] Fig. 3 shows a first embodiment of the artificial birefringent device 200. The incoming (linearly polarized) light is split up by a beam splitter or fiber coupler 210 and guided along the two different paths. One (typically short) path returns the signal with its original polarization. A second path, which has a geometric length difference of ΔL, returns the signal in its orthogonal state of polarization, e.g. by providing a Faraday Mirror 220. After recombining the light of the first and the second path, the state of polarization of the combined signal depends on the wavelength of the optical signal.

[0033] Fig. 4 shows a further embodiment of an artificial birefringent device 200, preferably made of PMF components. The incoming (linearly polarized) light is split up by a polarization dependent beam splitter 250 into light beams having orthogonal states of polarization, guided along the two different paths with the length difference of ΔL, and recombined with the still orthogonal states of polarization. The state of polarization of the combined signal again depends on the wavelength of the optical signal. In order to provide both paths with substantially the same optical powers, a polarizer 260 might be inserted before the polarization dependent beam splitter 250 in order to polarize the incoming light to 45° with respect to polarization states provided by the polarization dependent beam splitter 250.

[0034] The artificial birefringent device 200 allows creating an almost arbitrarily selectable delay difference between two signal fractions. The delay difference is defined by the length difference of the fibers ΔL. For this setup Equation 2 changes to:

$$\Delta\lambda \approx \frac{\Delta\alpha_1 \cdot \lambda^2}{2\pi \cdot n \cdot \Delta L} \qquad \text{(Equation 5)}$$

where n represents the refractive index of the fiber. As an example, getting a PDL or PMD measurement resolution of 1 pm can be achieved by a length difference ΔL=1.5m.

Claims

1. A system for measuring a polarization dependent parameter of an optical device under test - DUT - (30), comprising:

   an optical source (10) adapted for providing an optical stimulus signal at variable wavelengths,

   a polarization translator (20) being adapted for translating the polarization state of the optical stimulus signal applied from the optical source (10) at its input to its output in a deterministic way dependent on the wavelength of the optical stimulus signal, and

   a receiving unit (40) adapted for receiving an optical response signal from the DUT (30) to the applied optical stimulus signal, and

   an analyzing unit (60) adapted for analyzing received optical response signals for different wavelengths for determining values of the polarization dependent parameter of the DUT (30).

2. The system of claim 1, wherein the polarization translator (20) provides the translation of the polarization dependent on the wavelength by using birefringent properties.

3. The system of claim 1, wherein the optical source (10) is adapted to provide a variation of the wavelength over the time, and the polarization translator (20) is adapted to provide a variation of the polarization over the time in accordance with the variation of the wavelength over the time provided by the optical source (10).

4. A method for measuring a polarization dependent parameter of an optical device under test - DUT - (30), comprising the steps of:

(a) providing an optical stimulus signal at variable wavelengths,

(b) providing a polarization translator (20) for translating the polarization state of the optical stimulus signal in a deterministic way dependent on the wavelength of the optical stimulus signal,

(c) receiving an optical response signal from the DUT (30) to the applied optical stimulus signal, and

(d) analyzing received optical response signals for different wavelengths for determining values of the polarization dependent parameter of the DUT (30).

5. The method of claim 4, wherein:

in step (a) the optical stimulus signal is provided with a variation of the wavelength over the time, and

in step (b) the polarization state of the optical stimulus signal is varied over the time in accordance with the variation of the wavelength over the time provided by step (a).

6. The method of claim 4 or 5, wherein in step (a) the wavelength of the optical stimulus signal is varied in a way that it does not hit a Principle State of the Polarization of the polarization translator (20), so that the output signal of the polarization translator (20) will follow a trajectory on the Poincare Sphere in a deterministic way.

7. The method of claim 4 or any one of the claims 5-6, wherein in step (d) several measurement points measurement points defined by the wavelength and the polarization state are analyzed together for determining one value of the polarization dependent parameter of the DUT (30).

8. The method of claim 7, wherein the wavelength range for such measurement points to be analyzed together is selected that the one value of the polarization dependent parameter of the DUT (30) can be considered as substantially constant in that wavelength range.

9. The method of claim 4 or any one of the claims 5-8, wherein step (d) executes at least one of the algorithms: interpolation of neighboring measurement points, combining four measurement points using the Mueller Matrix analysis, or combining two measurement points using the Jones Matrix analysis.

10. The system or method of any one of the above claims, wherein the polarization dependent parameter is one of polarization dependent loss, polarization dependent group delay, differential group delay, or polarization mode dispersion.

11. A software program or product, preferably stored on a data carrier, for executing the method of claim 4 or any one of the claims 5-10, when run on a data processing system such as a computer.

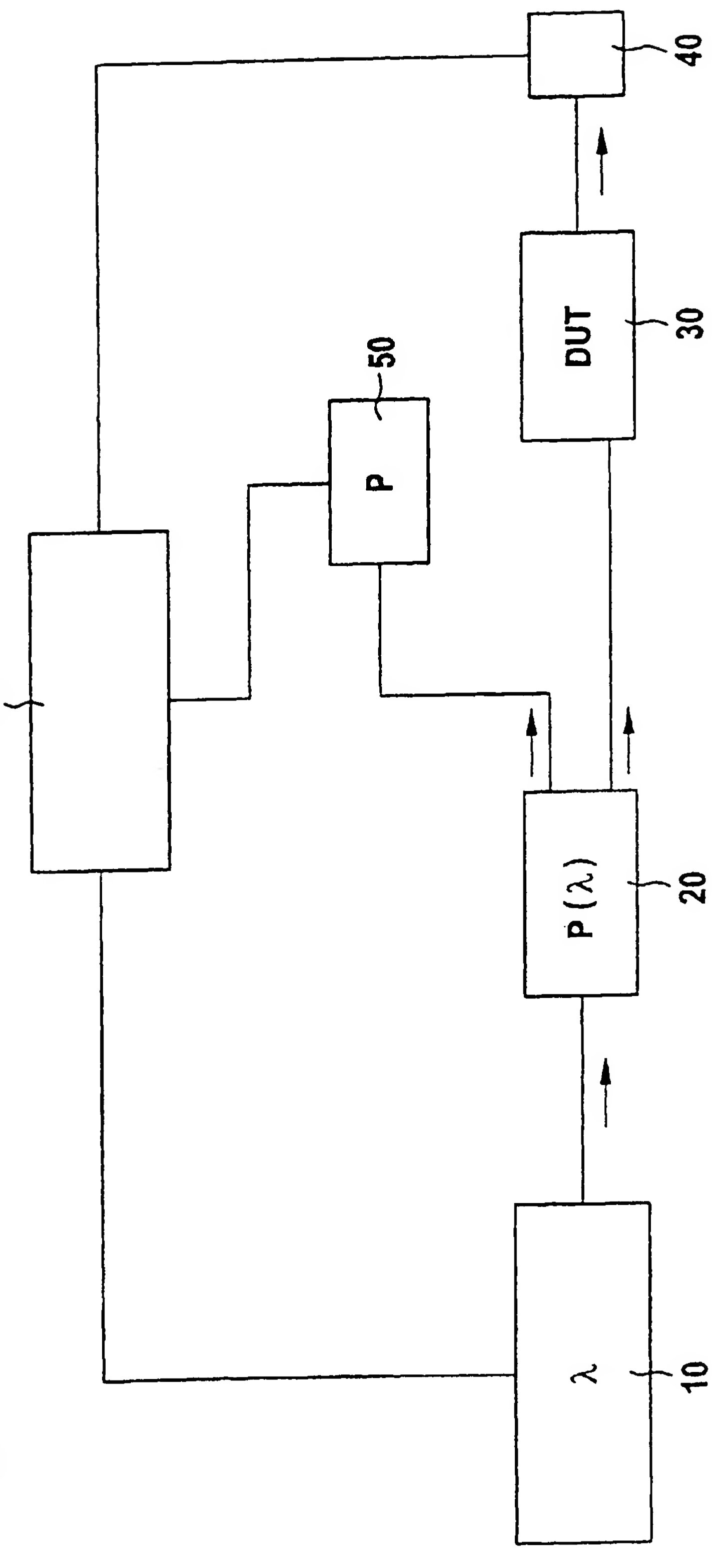


Fig. 1

Fig. 2

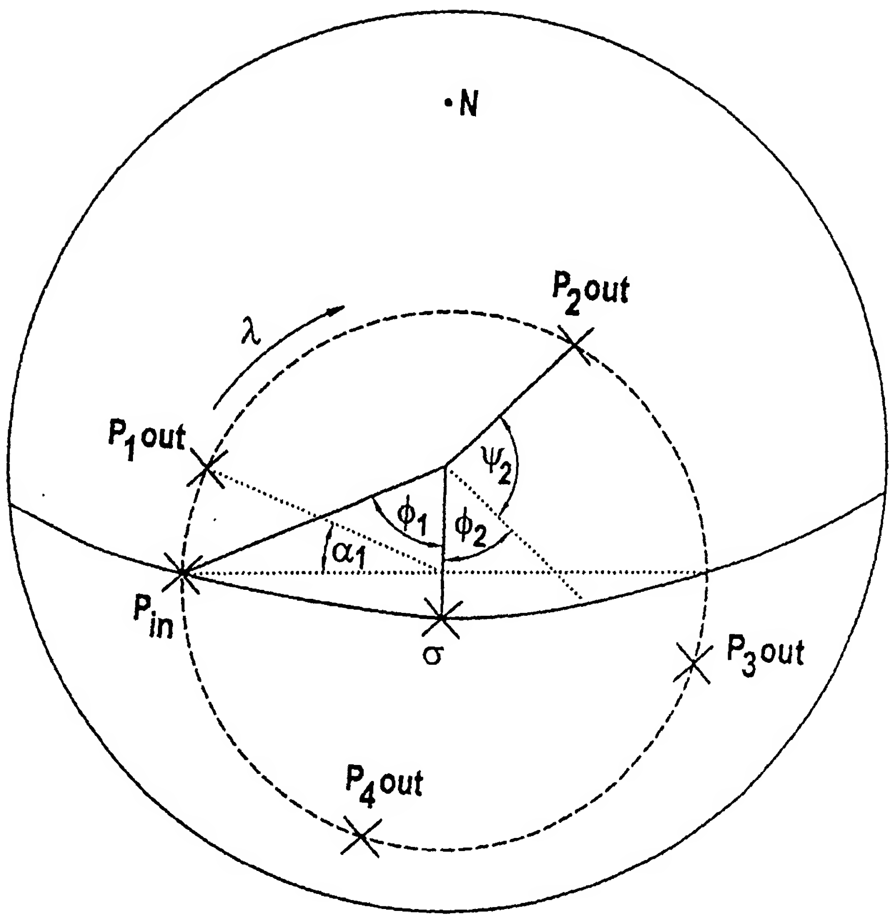


Fig. 3

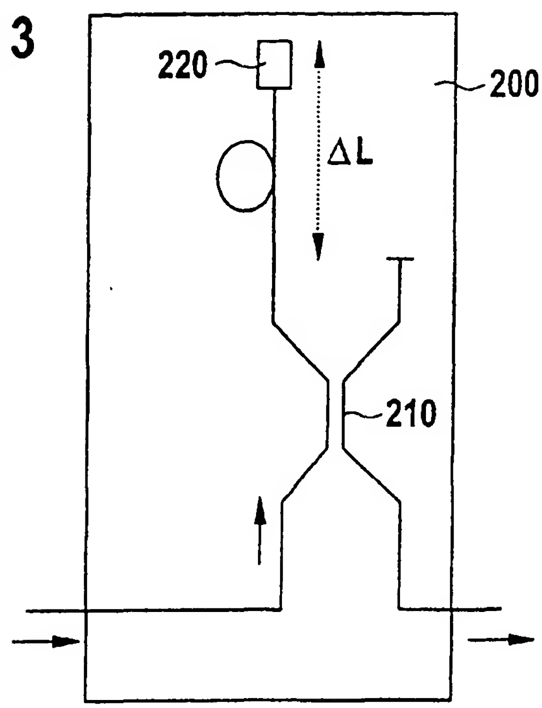
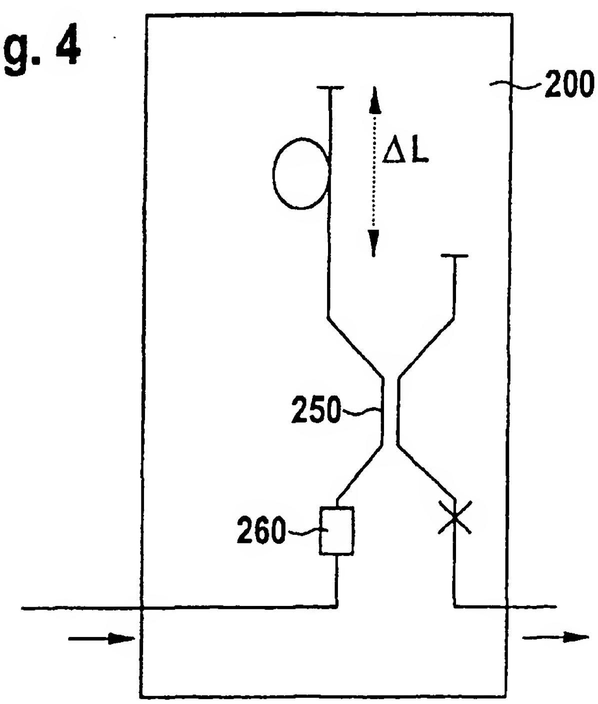


Fig. 4



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EUROPEAN SEARCH REPORT

Application Number
EP 01 11 3886

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 6 229 606 B1 (WAY DAVID ET AL) 8 May 2001 (2001-05-08) * the whole document *	1-11	G01M11/00
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
			G01M

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	12 December 2001	Zafiropoulos, N

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6229606 B1	08-05-2001	AU 7871100 A	23-04-2001
		WO 0128134 A1	19-04-2001

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